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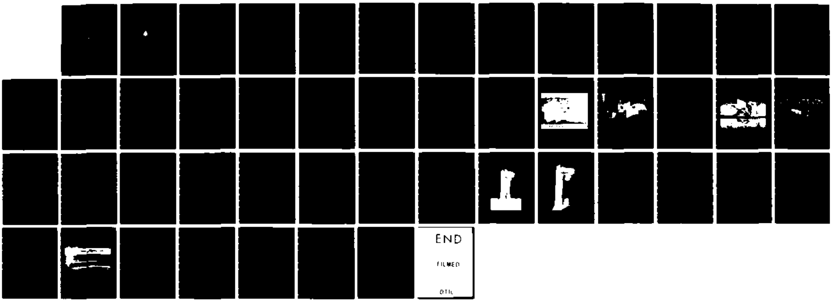

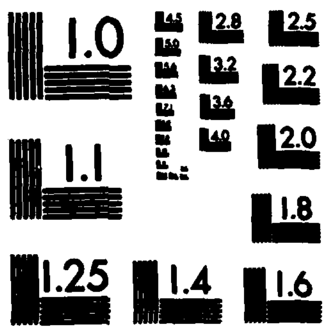

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A Miniature Urethane Molded Acoustic Transducer

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Christopher Van Rensselaer Dunn

August 1984

Technical Report

Prepared for the Office of Naval Research under contracts N00014-82-C-0019 and N00014-79-C-0071; and for the National Science Foundation under grant OCE-8014938.

Approved for public release; distribution unlimited.

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Robert C. Spindel, Chairman
Department of Ocean Engineering

Abstract

The development of a reliable miniature molded transducer for the Williams/Koehler acoustic current meter, BASS (Benthic Acoustic Stress Sensor) is documented. The procedures developed and components selected for manufacturing the transducer assemblies are documented as well as some of those rejected.

Engineering tests performed to ensure reliable performance in the field are outlined and discussed as well.

The transducers are now routinely molded with great success (over 1200 operational transducer months to date) and commercial sources are being investigated.

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I. Introduction

For the past several years, development of a reliable transducer unit for the Williams/Koehler acoustic current meter, BASS, has been underway. This report documents the development of that transducer.

The BASS (Benthic Acoustic Stress Sensor) current meter is intended to measure turbulence in a reversing flow field. This is the overriding design factor and manifests itself in all aspects of the current meter. All parts of the velocity sensor were kept as small as practical in order to make a measurement of naturally occurring turbulence, not the wake of the current meter itself. Flume calibrations were performed to verify the current meter's performance (Grant, Newman and Williams, in preparation).

In addition to the requirements for small size, the extreme sensitivity of the current meter to changes in the physical characteristics of the transducer element required that the final assembly be exceptionally stable, both physically and electrically.

II. Transducer Requirements

The BASS current meter is designed to be used in both coastal and deep ocean boundary layer studies. The system is subjected to a wide range of operating conditions, from hot sun on the deck of a ship, to near freezing temperatures on the abyssal plain. Pressure ranges from a few pounds near the surface to a crushing 10,000 psi. Deployment times range from a few hours to several months, while sampling intervals range from 5 Hz continuously for days to one sample every 10 minutes. A transducer assembly of extreme versatility and reliability is called for to meet these conditions.

Practical considerations in the field require that the transducer be

easily serviced since failures do happen. Because many transducers are needed for a single current meter array, the assemblies must be reasonably easy to manufacture, and only modestly expensive. The transducers must be impervious to salt water leakage and absorption, weathering, and must have an operating lifetime that is consistent with their cost and mission. Expensive transducers that wear out quickly are not acceptable, nor are inexpensive ones that fail prematurely. A two to three year life cycle was considered adequate for initial designs.

In summary then, the basic design criteria for the transducer were:

1) physically compact, low profile, low flow disturbance;
2) stable, drift-free performance;
3) high reliability and long life under a wide range of pressure, temperature, and duty cycles;
4) readily manufactured in quantity at moderate cost;
5) easily serviced units.

III. Design Description

3.1. Configuration

Many different methods for building transducer units were tried throughout the development of the BASS current meter. Some were more successful than others and survived, while the total failures were quickly abandoned. Because BASS is a vector measuring current meter, a minimum of three acoustic paths are required to resolve the current's u, v and w components. Difficulties in the early prototypes led to the addition of a fourth acoustic axis as a redundant, back-up channel, ensuring that at least three components of velocity would be measured. This characteristic has survived to the current models of

BASS. The eight transducers required for the four acoustic axes are arranged symmetrically around a pair of opposing rings which define the sensor volume (Fig. 3.1). The dimensions of the volume are based on the characteristics of the intended flow measurement.

The most straightforward approach to manufacturing the required transducer arrays is to fix four transducer elements in a single ring. An early version of the BASS sensor pod was made in just this fashion, machining sensor rings from PVC pipe and then gluing transducer elements into place with epoxy. The process was labor intensive, requiring an inordinate amount of precision machining and assembly work. Failure of a single transducer crystal resulted in an entire ring being discarded; there was no easy fix for the broken unit. Large arrays of the PVC rings were also impossible to align and fixture within the tolerances required to make the sensitive turbulence measurements. A new approach was needed.

3.2. Selection of Material

The goal of manufacturing many transducers at a moderate cost led to the decision to investigate the possibility of molding the transducers with a plastic material. Plastics have many properties that make them attractive for underwater use. They are waterproof, they don't corrode, they are durable, and they are inexpensive. Most of the costs associated with plastics are set-up charges, tooling in particular. Because of the demands for a durable, reliable unit, polyurethane was chosen as the material for the transducer body. Epoxy was considered as well, but trial pieces did not prove as successful as the urethane parts. Other plastic materials were not considered because they were a completely unfamiliar technology.

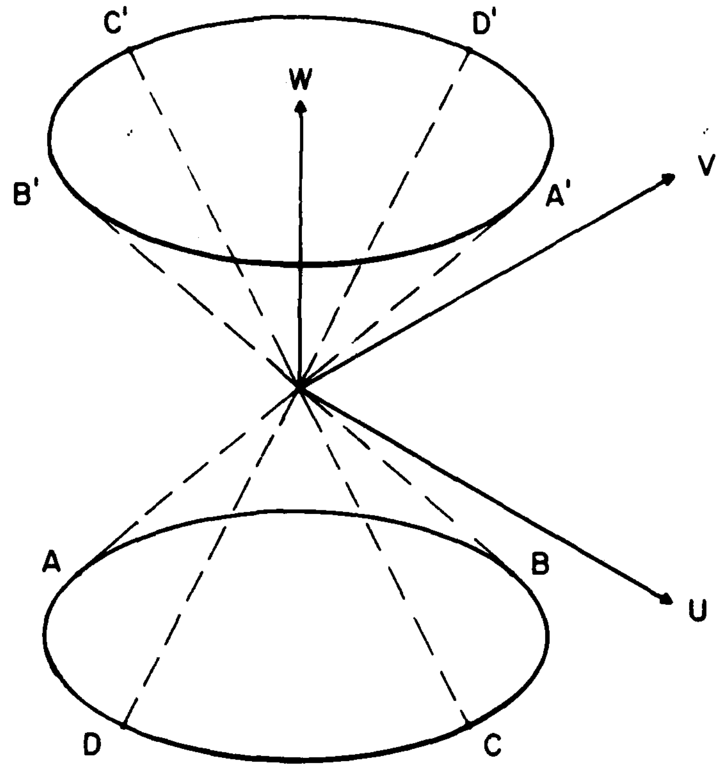

Figure 3.1. BASS sensor volume schematic showing the four acoustic paths (15 cm path length) with the current velocity components, u, v, and w.

3.3. Transducer Evolution

The BASS current meter measures stress through the bottom boundary layer with a two to five meter long array of cable connected velocity sensors. The sensitivity of BASS requires that this array be exceptionally rigid. Furthermore, the wake from the array must not contribute to the flow signal measured by the current meter. To meet these needs, a lightweight stainless steel truss structure was designed, providing the spatial stability for the acoustic transducer elements.

At this point, the concept of molding four ceramic transducers into a single ring was abandoned. The idea, although basically sound, turned into an assembly nightmare of trying to force rigid rings through an unyielding truss. An attempt was made to mold transducers directly to the cabling, but continuing failures of individual elements and dimensional instability of soft urethanes needed for this type of arrangement forced the selection of a design incorporating individual, rigid transducers. As an added benefit, these individual transducers use a miniature underwater connector making field replacement a simple plug-and-go operation.

A drawback to the rigid urethane body was the need to complete the encapsulation of the ceramic transducer with an additional pour of a different urethane material. The precise fixturing of the transducer element in the mold is done by attaching the front face of the ceramic directly to the mold, leaving it bare after the initial urethane pour. A soft urethane with acoustic properties similar to seawater was chosen as the material to cover the front face with. The acoustic matching to seawater eliminates concerns about possible effects of the refraction of the sound pulse from the transducer element.

A complete listing of parts and suppliers for the materials required is included in Appendix III.

3.4. Engineering Testing

An initial batch of approximately two hundred transducers were manufactured over a two year period for use in BASS systems. During this time period, the BASS electronics were thoroughly tuned and many design problems were corrected. Field deployments and lab tests of BASS current meter arrays were becoming routinely successful except for nagging mysterious failures of acoustic channels. Because of the reliability of the electronics package, our attention was directed to the cabling and transducers as the source of the problem. Many of the failures were intermittent and difficult to trace. Some transducers had failed in a way that allowed them to continue functioning, but their electrical properties had drifted giving seriously fluctuating zero values and erroneous current measurements. The problems fell into three broad categories: 1) weak or noisy signal; 2) unstable zero; 3) intermittent electrical contact, each of which could be separately investigated. All of the molded transducers had been tested thoroughly at the time of their manufacture and assigned an identifying serial number. The tests included measurement of signal strength and beam pattern. Using this data as a reference point, it was possible to construct life histories of the transducers, measuring quantitatively the changes in transducer behavior.

Close examination of the transducer population revealed that over time the urethane bodies had distorted and some of the ceramic elements had become

discolored. The worst examples of these types of transducers were selected for rigorous testing and analysis. Steering changes and seawater leaks were now suspected as problems, indicated by the deformation and discoloration, respectively.

3.4.1. Tests for Sea Water Leakage

Leakage of seawater into the molded transducer assembly was suspected as a major problem, although it was not clear what the leakage path was. A group of transducers known to have failed and then recovered was selected for a test group. In addition, functioning transducers with badly discolored ceramic elements were tested. A new unit, which had never been exposed to seawater was added as a control. The transducers were assembled to a cable harness and then soaked in seawater for a period of three months. At various times during the soak, the capacity and dissipation of the transducers were measured. An increase in either capacity or dissipation would indicate the presence of seawater flooding the ceramic element of the transducer. The test results are summarized in Figures 3.2 and 3.3, plots of the measured electrical characteristics over time.

The trend of the plots is clear, the electrical characteristics of the flooding transducers change over time. A small change in capacity, such as that due to pressure, is not serious; the current meter circuit is designed to be insensitive to it, but large changes are serious (Williams and Koehler, in press). During the soaking phase of the experiment it was observed that the soft urethane cover of the transducer was separating from the body and after a few days of soaking, the cover could be pulled completely off. The face was not bonding to the transducer body and seawater was flooding the ceramic element. The immersion test was continued, however, to make certain that the

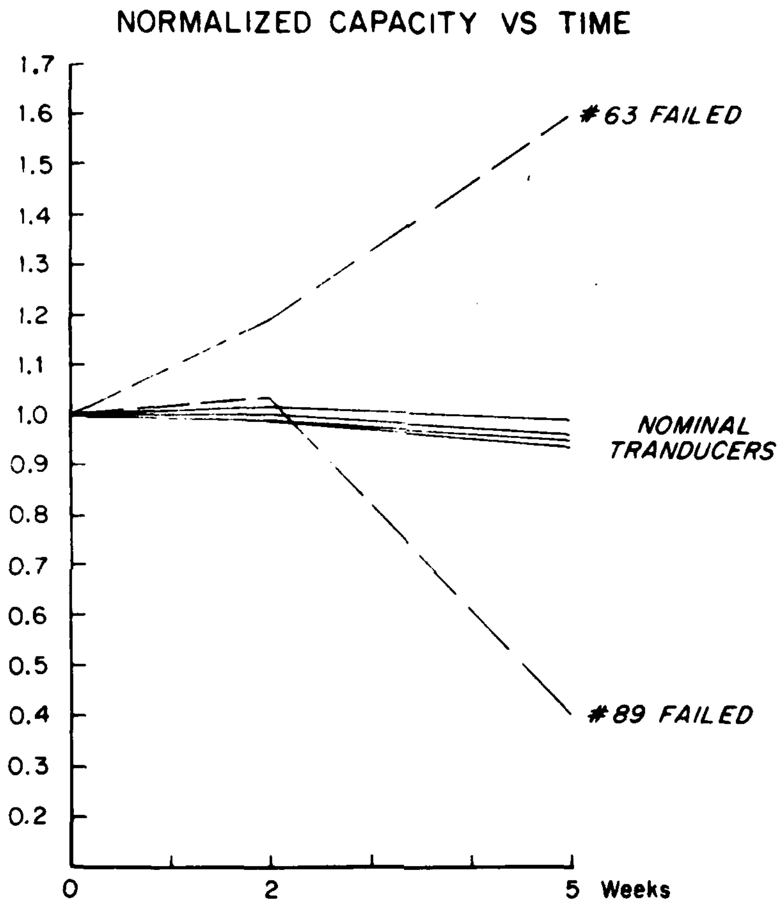

Figure 3.2. Electrically, the normal transducers look like capacitors. Large changes in their capacity indicate seawater contamination.

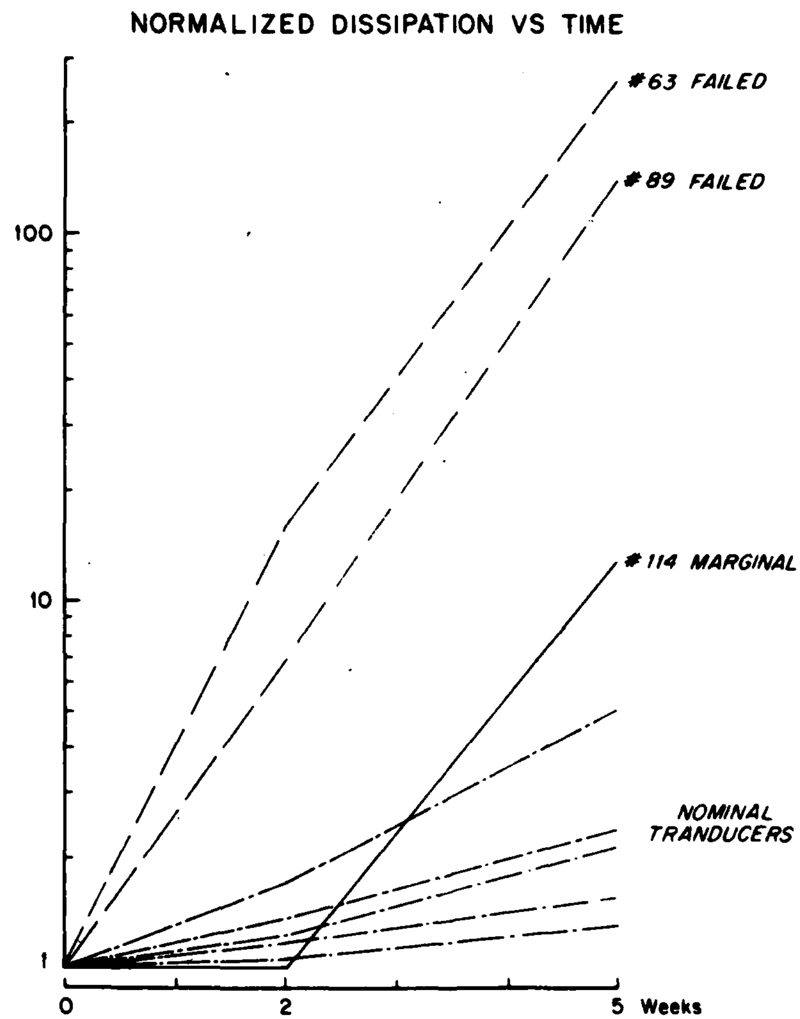

Figure 3.3. The dissipation of the transducers provides a more reliable indication of failure. Seawater leakage causes a 100 fold change in the measured dissipation.

problem had been correctly identified. Urethanes tend to absorb small amounts of water and it was important to demonstrate that this absorbtion was not a source of trouble. Soaking tests with bare ceramic elements were made to identify the symptoms of seawater flooding unambiguously. The bare elements were found to behave exactly as the failed molded parts. Water absorbtion by the urethane did not appear to have any discernable effect on the electrical properties of the molded transducers.

3.4.2. Tests of Deformation

One early version of the molded transducer parts involved potting a ceramic element directly onto a length of cable using a flexible urethane. These soft transducers were extremely unreliable because they distorted easily. Individual transducers made of rigid urethane were molded and used satisfactorily in several seasons of field experiments, but over the course of time many of them visibly distorted due to cold flow. This distortion was suspected as a source of transducer failure and was investigated. As part of the quality control process in fabrication, individual transducers are steered, measuring the beam pattern and deflection against a standard reference. All transducers are tested and the results are logged. Using this information, it was possible to construct a life history of 18 of the most distorted transducers, comparing before and after beam patterns. As part of this comparison, a statistical analysis of the steering process itself was made so that real problems of transducer alignment could be separated from uncertainties in the test procedure. The detailed results are contained in Appendix 1, but it was found that

1) There was no basis to suspect physical distortion for systematic transducer failures related to steering because the observed steering changes of the distorted transducers were of the same order as the uncertainty of the steering process.

2) The distortion stressed the solder connection on the ceramic elements, leading to intermittent and failed electrical contact.

Cold flow turned out to be a problem, but not for the reasons initially suspected. The acoustic beam was not being steered off axis by the distortion, but mechanical failure was occurring inside the molded transducer assembly.

3.4.3. Tests of Pin Contacts

Experience with BASS systems in the field had shown up a serious problem with the underwater connector portion of the transducer assembly. On many of the acoustic axes (as high as 15 percent) intermittent contact was causing the loss of velocity channels. Transducers that tested out properly on the surface would fail at depth, while others would cease functioning for no apparent reason. The electrical contacts in the underwater connector consisted of pins molded into the transducer stem, and mating sockets molded into the female connector sleeve. With the connector assembled, the pin was inserted in the socket. Metal to metal contact was maintained by spring leaves within the miniature socket.

Studying the troublesome connector parts revealed the presence of urethane which had leaked inside the metal shelled socket during molding. Test assemblies were made with sockets that had been grease filled to exclude

urethane during molding, but these proved no more successful than the flooded contacts. The flooding clearly was not at fault.

Reliable electrical contact depends on solid metal to metal contact which is accomplished with a spring as part of the contact pair, usually in the socket. In the miniature contacts used, the springs were located in the socket half of the contact. When the pin was inserted in the socket, the spring deflected, exerting pressure on the pin. This did not work for the miniature contacts because the deflections were so small relative to the spring length. A new type of contact was needed, one with a better spring.

One type of pin and socket pair that offered promise was a combination with a hollow tubular socket and a twisted spring pin. The cantilevered length of the spring was shorter which resulted in a higher force between the two parts of the contact pair, and thus, better metal to metal contact (for the same deflection, a shorter cantilever must be loaded with a higher force). It was possible to confirm this relationship experimentally by measuring the withdrawal force of an assembled pin and socket combination. The spring pins had a consistently higher withdrawal force than the spring sockets (see Appendix 2). The spring pin, hollow socket combination also offered the advantage of being easy to clean after molding. No longer was urethane flooding a problem, although the contact parts are still grease filled during assembly to prevent flooding. Approximately 200 transducers have been manufactured using this type of contact without a single failure in the laboratory or in the field.

IV. Manufacture

4.1 Molds

The mold for the urethane transducer is machined from 7075 aluminum alloy. This material is reasonably easy to work and is durable enough to provide a mold which lasts for several hundred pours. If mishandled or improperly cleaned with solvents, the mold is degraded more quickly. A Teflon coating applied to the mold eliminates the need for mold release. This is extremely helpful in the molding process because mold release causes many problems in handling and fabrication.

The use of a rigid urethane material required that the aluminum mold have sufficient draft to allow molded parts to be removed easily without breakage. The mold is filled with potting compound from the bottom up, flushing air out of sprue holes at the top. The risers from the sprue holes are cut off after curing and demolding.

4.2 Molding

4.2.1 General Notes

For successful molding, all molds and parts must be clean. Sources of contamination are handling, air lines and regulators, and airborne materials. Dirt, dust, grease, moisture (including humidity) and mold release can cause failure of molded urethanes. Surface contaminants, such as grease, generally cause bond failure. Reactants, such as moisture, cause bubbling.

Before molding, all items to be used must be degreased with solvent, and then oven dried. Molds should be blown clean with dry nitrogen gas only, NOT compressed air. All containers, mixing equipment and handling equipment must also be cleaned and kept free of contamination. Mold release, when required, should be used sparingly, and applied to the molds in a fume hood or in a remote location. Teflon coated molds are currently in use and are preferred over non-coated molds.

4.2.2. Pre-mold

The connector stem of the transducer is pre-molded in an RTV mold. This procedure gives two benefits: 1) all flashing is eliminated from the connector area; 2) assembly is facilitated. The contact pins are soldered directly to a 1 1/2" length of 26 gauge bus wire. These pins are placed in the RTV mold, carefully adjusted for length of projection and position, and then captured in DP-10767. This urethane is injected with a syringe into a heated mold (80°C). The mold is filled from the bottom up, flushing air as the fluid level rises. The part is cured at elevated temperature (80°C) in an oven, then extracted from the mold. The RTV molds have a limited lifetime and should be used for approximately 10 pours and then discarded. Various types of RTV were tested. DC L RTV and DC Silastic E RTV were found to give excellent results.

The locator receptacles for the pin contacts are injected with DC-4 grease prior to assembly and molding to shield the pin contacts from contamination with urethane.

4.2.3. Final Mold

This operation requires assembly of the transducer components in the mold (Figure 4.1).

A number 2-104 "O"-ring is slipped over the pre-molded transducer stem. The stem is abraded, cleaned and then placed into the lower half of the aluminum mold, capturing it. The mold is not yet assembled.

A ceramic element is fixed to its locator plug using a pre-cut disc of double sided tape. The wires are oriented so they can be routed in the mold without touching it. The leads from the transducer are soldered to the pin wires in the pre-molded part and trimmed. The negative transducer face is connected to the pin closest to the injection port. This port will become the locator bump on the finished transducer. After checking the alignment of the transducer stem, the mold is closed and then heated in the oven. After heating, CONAP DP-10767 is injected into the mold. Sufficient urethane is injected to flush out trapped air bubbles. Any moisture, grease, flux or other contaminant in the mold will cause severe bubbling of the DP-10767 urethane. The potted transducer is cured in its mold at 80°C for approximately four hours and then demolded (Figure 4.2). At this point, the transducer is inspected. The ceramic element must be exactly parallel with the 45° front face of the molded part. If the ceramic is visibly misaligned, even slightly, it will not be satisfactory. The transducer is also checked electrically for capacitance and dissipa-

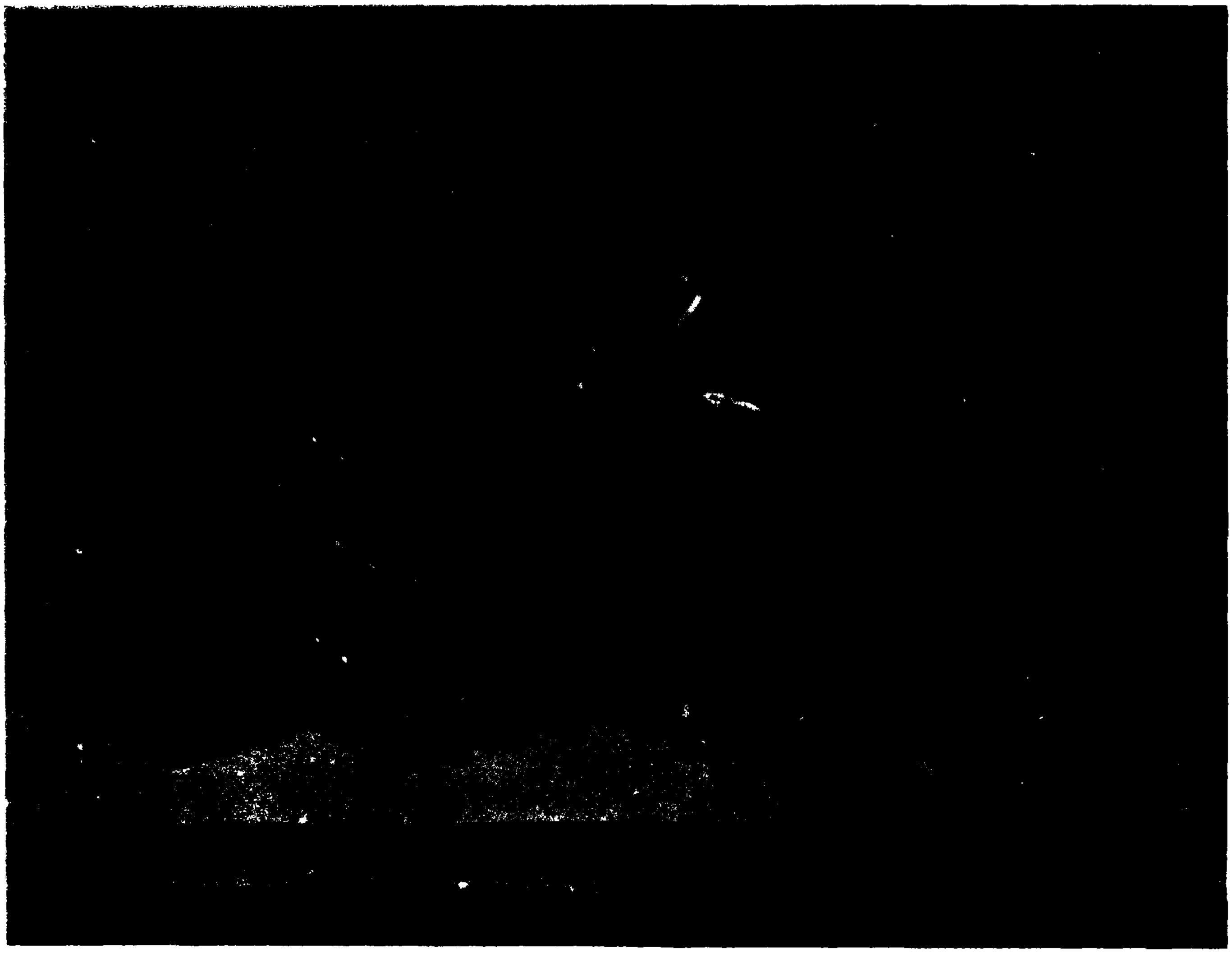

Figure 4.1. Mold Assembly. The partially assembled mold is ready to receive the premolded transducer stem and ceramic element.

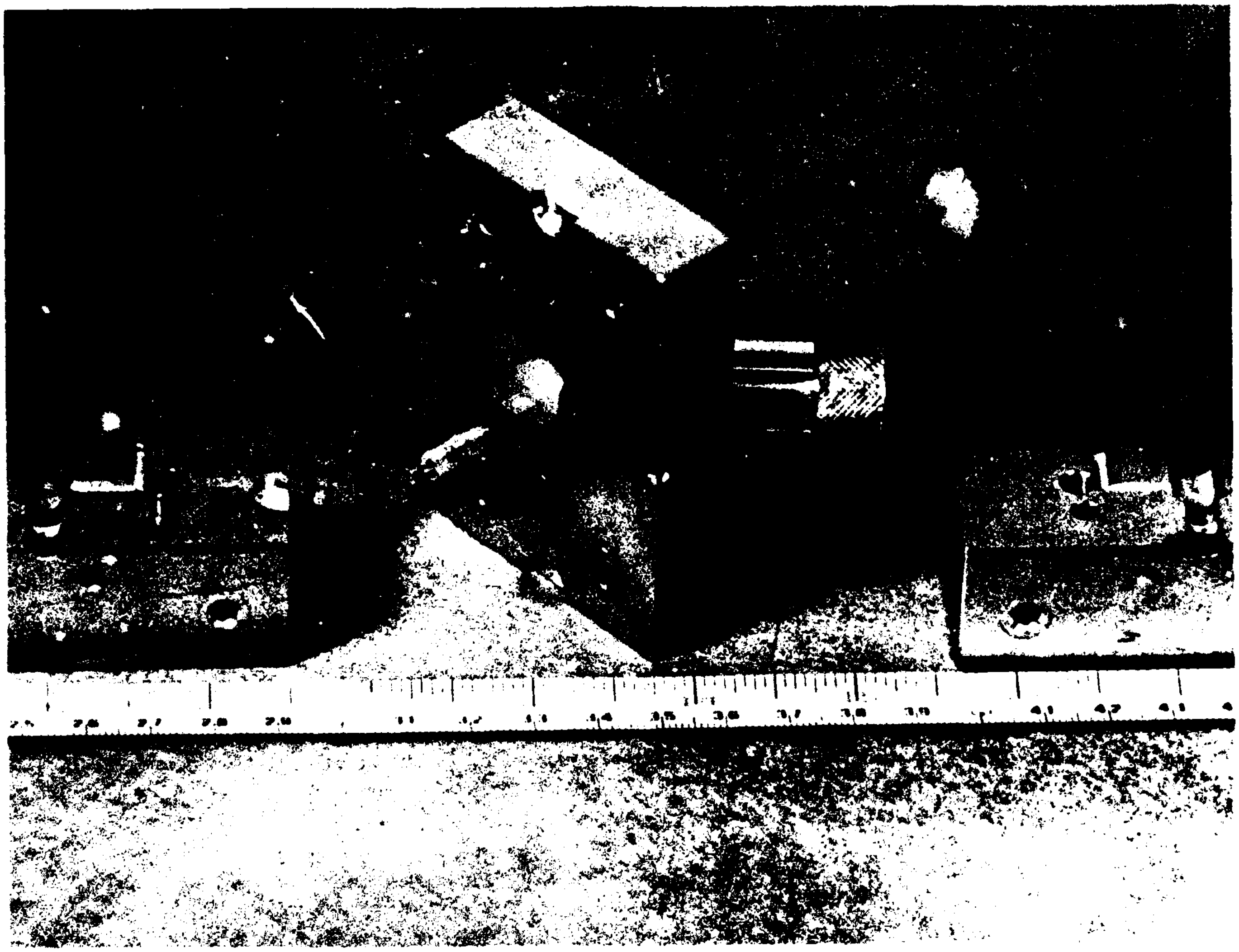

Figure 4.2. Transducer Demolding. The cured transducer is ready for demolding. The O-ring seals the mold, preventing flashing from forming on the connector stem.

tion. A broken solder joint will show up at this point. The "O"-ring is left on the transducer stem, but is not functional.

4.2.4. Transducer Face

The pouring of the EN-4 face is a critical step in fabricating the finished transducer. After completing the tests of the finished assembly, satisfactory transducers are prepared for facing (Figure 4.~~2~~3). The transducer face is wiped clean with solvent to remove traces of mold release and other contaminants. A disc of masking tape (printed circuit layout tape) is placed over the ceramic to protect it, and then the face of the transducer assembly is sandblasted to expose fresh, uncontaminated surface. Dry nitrogen is used in the sandblaster and all hoses and fittings must be free of dirt, oil and moisture. Only clean, fresh blasting grit should be used. Once the transducer face is sandblasted, the masking is stripped off, and the surface is cleaned using MEK. A light swabbing is adequate. CONAP EN-4 is dripped onto the clean, dry face using a hypodermic syringe until a thin, smooth, slightly convex layer covers over the ceramic element and the surrounding urethane. A good bond to the urethane substrate is essential to keep water out of the finished transducer assembly.

The transducer is supported with the face level and placed in a bell jar. A vacuum is carefully drawn to remove trapped air from the EN-4. The transducer is then transferred to the oven, keeping the face level, and cured for 24 hours at 80°C.

The transducers can be processed in batches much more efficiently than singly.

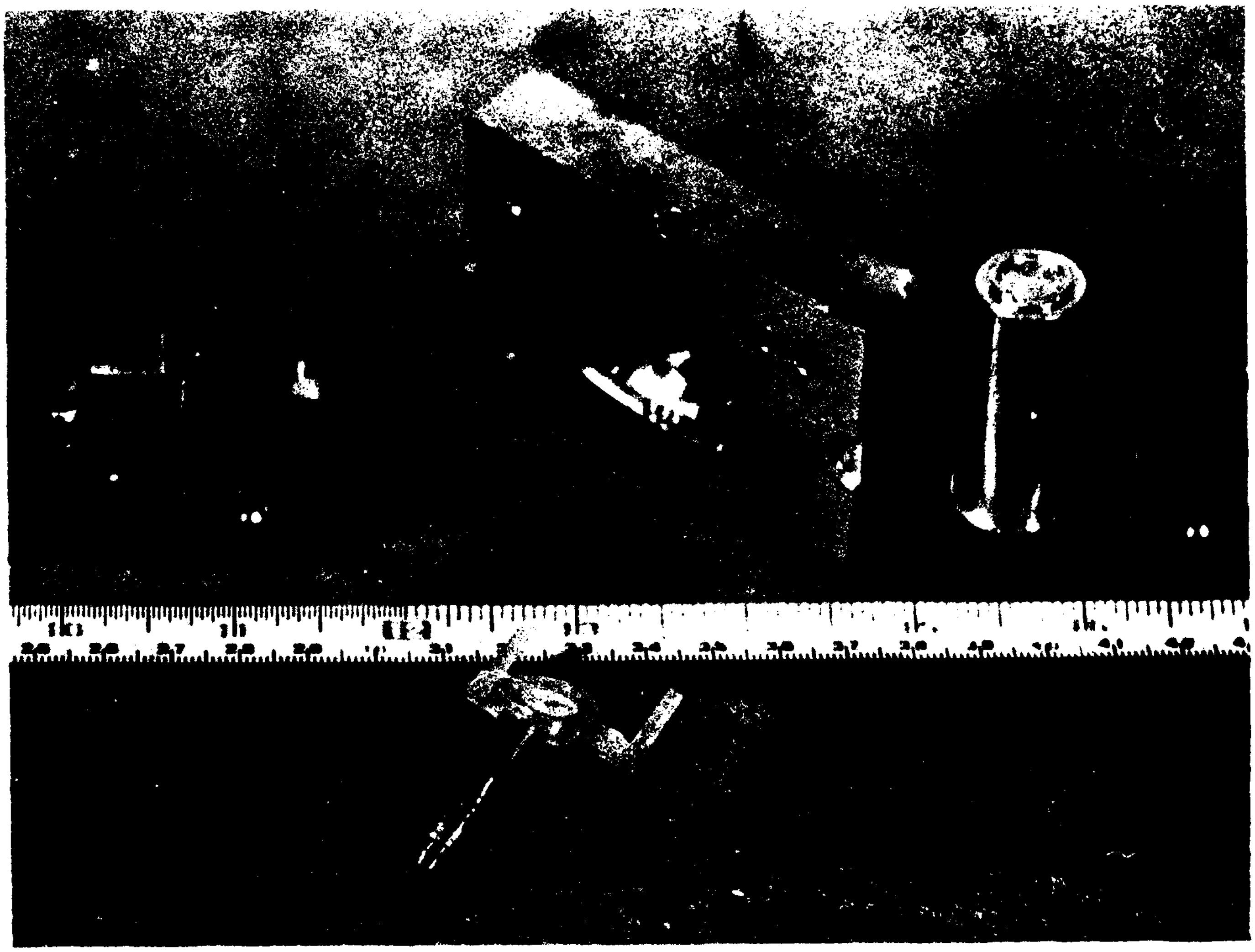

Figure 4.3. Completed Pour. The transducer assembly has been demolded and is ready for sandblasting prior to the final face pour.

Figure 4.4. Finished Transducer. The finished transducer ready for use. The twisted spring pins, O-ring and convex EN-4 face are visible.

Once the transducers are cured, they are inspected, assigned a serial number and checked electrically again.

The completed transducers are ready for use (Fig. 4.4).

4.3. Quality Control

Quality control is an important factor in manufacturing the transducer assemblies. Without continual inspection of the molded parts, errors and defects slip past and ultimately cause problems during an experimental deployment. In order to assure maximum reliability of the transducers, they are subjected to thorough testing throughout manufacture.

Initially, the individual components and materials are inspected for conformance to specification. In particular, electrical parts are tested before potting to eliminate the chance that a marginal contact or ceramic element is incorporated into a finished transducer. After each of the molding operations, the nearly completed subassembly is subjected to electrical tests and mechanical inspection before passing on to the next stage in manufacture. This continuing inspection procedure serves two purposes. First, bad components are weeded out before causing problems, and second, difficulties and failures in the manufacturing methods are caught and corrected on a daily basis keeping the overall success rate high.

When a transducer is completed, its testing continues. All transducers are tested for signal pattern and steering before final assembly to a BASS sensor cage. As a final check before deployment in the field, assembled sensor pods are subjected to electrical and acoustical testing both in the laboratory test tank and in the pressure tank.

The procedures for testing take time even though they have been streamlined by the use of specially made facilities such as switching equipment,

test tanks and pressure tank feed throughs. The time invested in quality control is well spent, however, because once deployed, there is no opportunity to replace or repair a faulty transducer. Our success in the field, over 1200 transducer months to date without a single failure, is due to the careful quality assurance work during manufacturing and assembly of the current meter.

V. Overall Success

5.1 Obtaining Design Objectives

As stated earlier, the primary goals for the BASS transducer are summarized as:

1) physically compact, low profile, low flow disturbance;
2) stable, drift free performance;
3) high reliability and long life under a wide range of temperature, pressure and duty cycles;
4) readily manufactured in quantity at moderate costs;
5) easily serviced units.

Our design effort met each of these goals without fail. The finished urethane transducer assembly is small in size and does not contaminate the flow measurement being made. This has been verified by extensive flume calibration by Grant and Newman. The stable performance of the transducer was the most difficult goal to achieve. Problems with seawater leakage and plastic deformation had to be identified and dealt with. Electrical reliability was difficult to ensure until it had been studied in detail. Careful and thorough testing of materials, components and molding procedures was required to attain

the required stability. This attention to detail resulted in a highly reliable molded transducer. In selecting the correct materials and assembly techniques, various prototypes were subjected to extremes of temperature, pressure, immersion time and duty cycles until the right combination of components and procedures was found. The transducers are readily manufactured using techniques and equipment available in a prototype shop. To date, over 400 individual assemblies have been molded, of which approximately one-half are the most recent version incorporating the techniques and components outlined in this report. The cost per unit, estimated at approximately $70, is not prohibitively expensive for the performance achieved. A search for a commercial manufacturer of the assembled transducers is currently underway with several promising leads.

Finally, the incorporation of a miniature connector into the finished transducer has resulted in a unit which can be quickly replaced in the event of failure in the field. In addition, the failure of any single transducer does not necessitate the replacement of the others associated with it, they are all completely independent units. Replacement of a transducer does require recalibration of the affected acoustic axis, though, since no effort has been made to make the transducers electrically identical. Calibration is simple enough that the extra expense and effort of electrical matching is not justified.

5.2 Operational Success

Approximately 200 transducers have been manufactured using the procedures outlined in this report. They have been used in BASS instruments deployed in experiments in the deep ocean (HEBBLE) and in coastal work

(CODE). The transducers have been used in an experiment lasting three months in the deep ocean, as well as one lasting four months in coastal waters. They have been cycled to 8000 psi and back to the surface repeatedly, and exposed to weather on the deck of a ship. Through all of this, the transducers have continued to perform without a single failure of any component. In addition, the calibration stability of the BASS current meter, which is linked to the integrity of the transducer, has been excellent over the course of the experimental deployments.

One potential trouble area that has yet to be addressed is that of biofouling. Biological material attached to the transducer faces can attenuate the acoustic signal and, more seriously, growth can obstruct the flow giving false current measurements. In the deep ocean, biofouling is not serious, but in shallow coastal waters the BASS sensor array provides a perfect home for all kinds of organisms. The application of anti-fouling paint is a standard practice to deal with this problem, however, the long term effects on the molded parts is uncertain.

Finally, the effects of sunlight on the molded urethane parts must be contended with. Ultraviolet radiation attacks and degrades the urethane compounds used in molding the transducers and the cable harnesses. To protect against damage, the transducer pods of the BASS array are wrapped in aluminum foil when they are exposed to sunlight for more than a few hours. The foil limits the exposure of the urethane parts and has helped to extend their service life tremendously.

VI. Summary

This report has discussed the development of a miniature acoustic transducer for the BASS current meter. It documents the procedures developed and components selected for manufacturing the transducer assembly as well as some of those rejected. The tests performed to ensure the integrity of the BASS transducers both during manufacture and prior to field deployment are outlined.

Acknowledgements

The development engineering was performed under contract with the Office of Naval Research and with grant money from the National Science Foundation. The author is grateful for the advice and guidance of Dr. Albert J. Williams 3rd and the expertise of Bruce Deslauriers and Ann Rams in fabricating urethanes. Thanks also to Ann Henry for helping prepare the manuscript and to Betsey Pratt for her graphics talents.

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Williams, A.J. and R.L. Koehler, "An acoustic travel time current meter for ocean boundary layer measurements," in preparation.

APPENDIX I

TRANSDUCER STEERING

I. Steering Procedure

All transducers molded are tested for beam pattern and steering. The individual transducers are mounted on steerable mount with micrometer adjustments for measuring deflection (Figure A-1.1, A-1.2). A mechanical pointer is used to define the physical, central axis of the transducers being tested, and then they are steered by observing their signal behavior with an oscilloscope. The beam is steered in two orthogonal directions, radially and circumferentially, and the points at which the signal falls off by 3 db from its peak value are noted. These values, along with the peak signal direction, are used to compute the angular width and displacement of the acoustic beam from the transducer under test. Transducers with an angular displacement of more than 1° in either the radial or circumferential direction from the central axis are rejected.

II. Sources of Error in Steering Procedure

A. Center Point Uncertainty

Uncertainties about the center of the transducer arise from two sources: 1) the actual location of the transducer's physical center, and 2) the location of its signal center.

1) The physical center is indicated with a pointer which is steered into place over a reference transducer. Over a period of two years multiple center readings were taken with the following results.

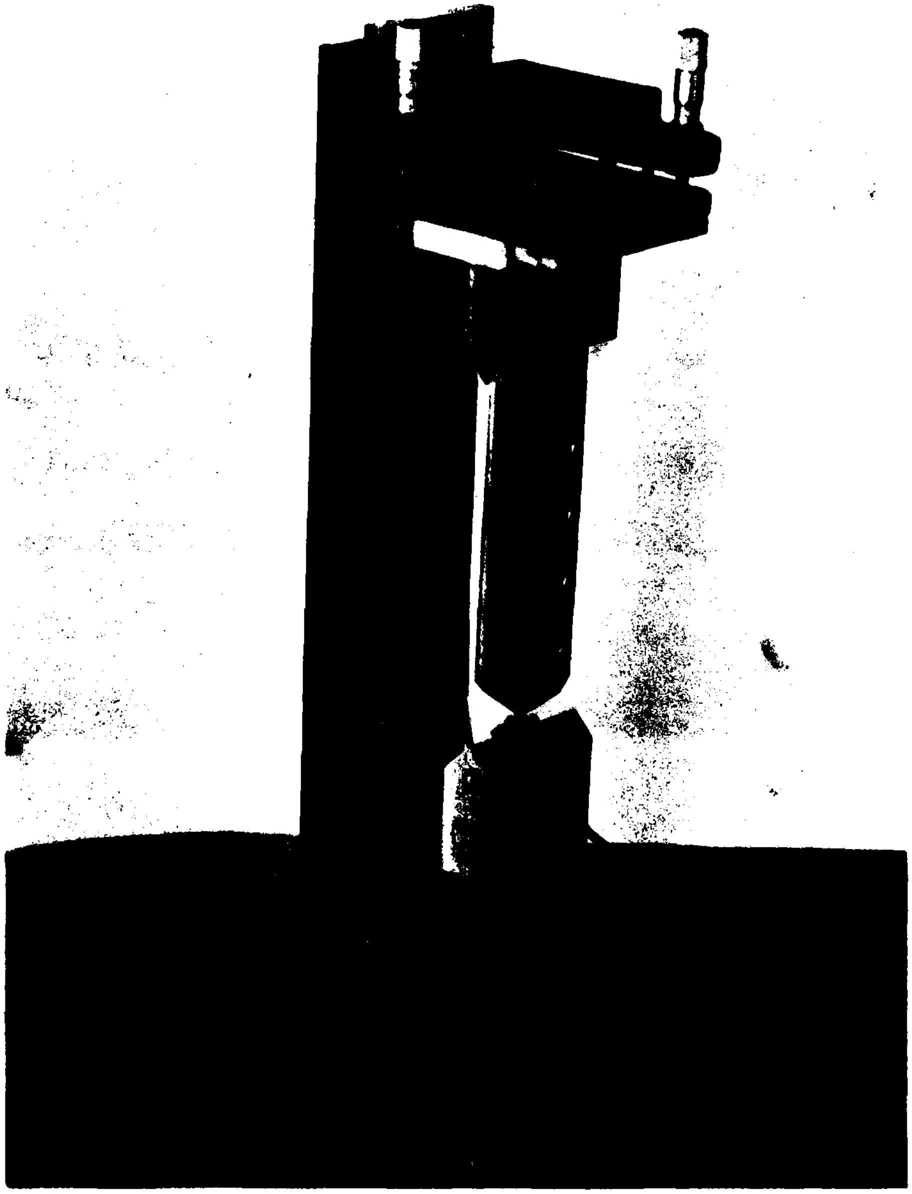

Figure A-1.1. Transducer test stand showing mechanical pointer and reference transducer.

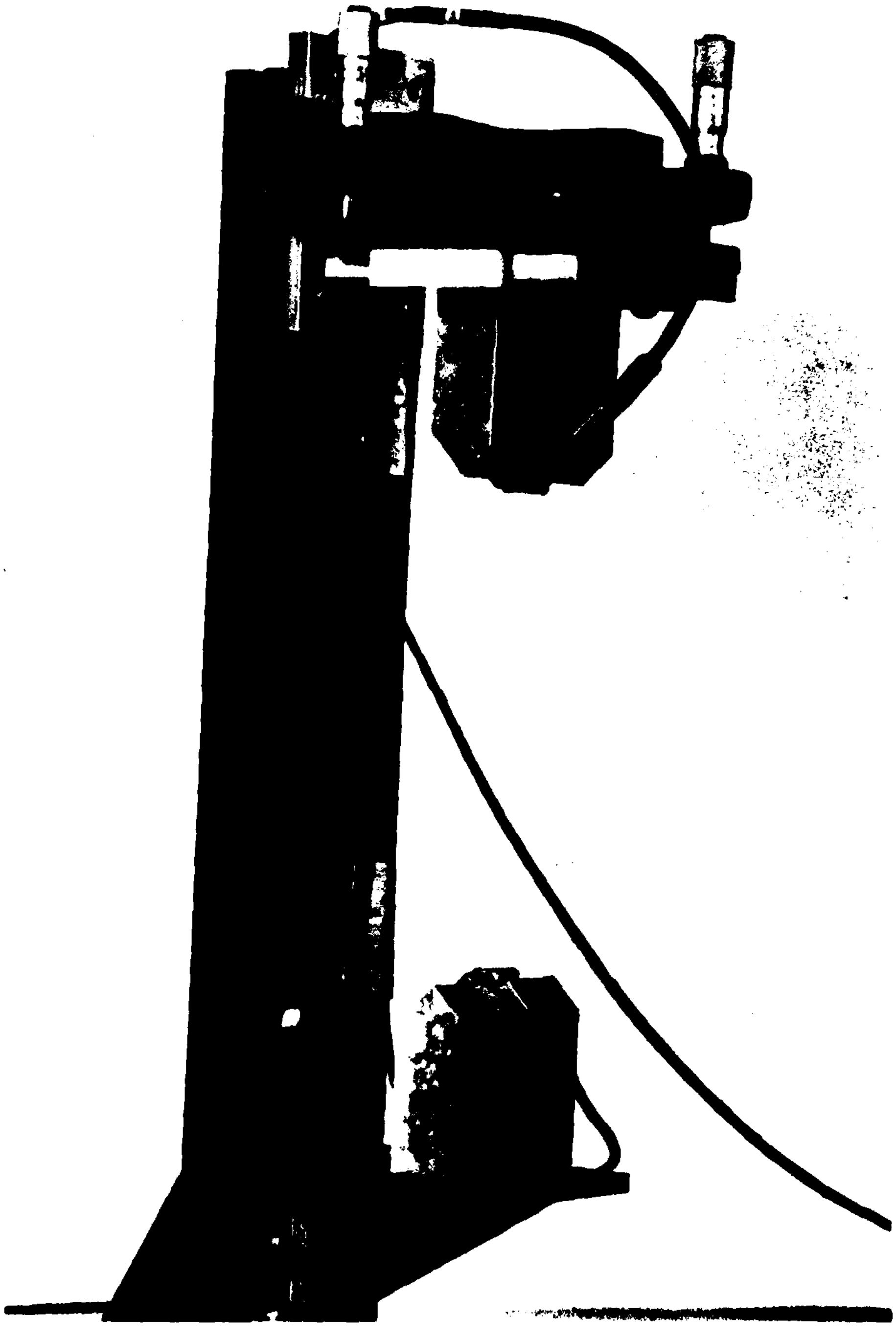

Figure A-1.2. Transducer test stand with test transducer installed for signal pattern measurement.

Uncertainty of Physical Center

in Radial Direction: $\pm$ .14°

in Circumferential Direction $\pm$ .41°

The aiming error is larger in the circumferential direction by about a factor of three.

2) There is also ambiguity associated with the exact center of the peak signal. When using steering data in which the signal is peaked, turned off center, and then repeaked, an estimate can be made of the uncertainty. Typically, the error when relocating the signal center is of the order of $\pm$ .10° in either the radial or circumferential direction.

B. Beam Width Uncertainty

The minus 3 db width is well defined and is not a source of significant error. A cutoff value is selected based on the measured peak signal strength. The cutoff is applied symmetrically to the observed signal. When the -3 db points are reached on either side of the peak signal, the steering displacement is recorded from the micrometer adjustment of the platform.

C. Absolute Signal Strength Uncertainty

The signal strength measured varies from test to test because the signal voltage applied to the reference transducer varies by as much as two volts from one test to the next. This makes comparison of the absolute signal strengths from one day with those from another difficult to interpret; on a given transducer the measured signal can vary as much as 60 mV (30% to 40% of overall signal). This variation in absolute signal strength turns out to be unimportant (within overall performance limits) because the measurement of

beam pattern and steering depends on relative changes of signal, not absolute. This makes it possible to compare one day's steering tests with another.

III. Resteering Test Results

Transducers are rejected when their signal center is displaced more than 1° from their physical center (as defined by a reference transducer and the mechanical steering device). Of the group of eighteen transducers tested extensively for distortion, four were found to have changed their original steering by a significant amount. The mean difference in beam deflection over the life of the transducers was found to be approximately .45° radially and .60° circumferentially (with a sample standard deviation of identical magnitude, Figure A-1.3). These values are not significantly different from the uncertainty associated with the steering measurements. The conclusion from this analysis is that:

1) Although a few of the distorted transducers had been rendered useless due to resteering problems, the cold flow of the urethane material was not chronic. For the most part, the changes in steering angles were not separable from the ambiguity associated with their measurement.

2) Despite the uncertainties associated with the beam pattern measurement, it is still possible to use the test to evaluate transducers at a misalignment level of 1°. Changes of less than 1°, approaching 1/2° lose significance against the noise in the measurement technique.

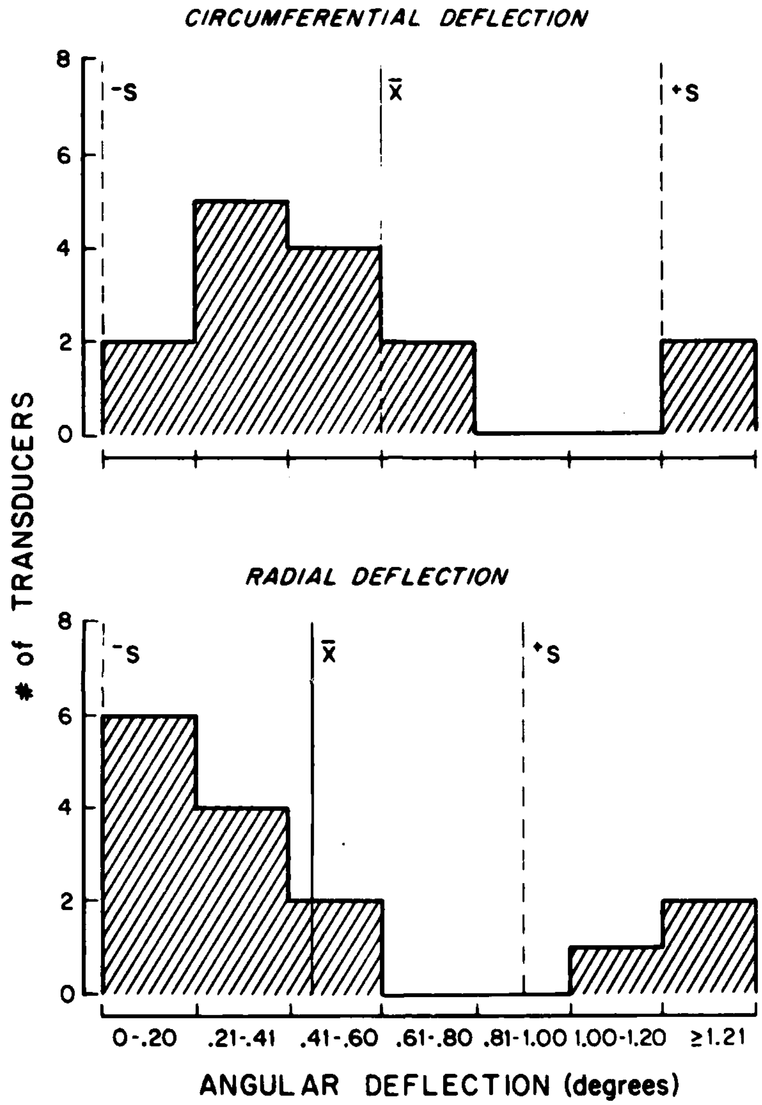

Figure A-1.3. Histograms of angular deflection due to the cold flow distortion of the transducer body.

A positive benefit of the analysis was the discovery that transducers could be accepted or rejected based on a visual inspection only. Through many observations it was noted that a 1° misalignment of the transducer element is visible under a low power microscope. This ability to inspect by eye has eliminated the need to perform the laborious steering test previously used as a final benchmark. Because of the time savings, it has been possible to produce transducers more rapidly and reliably.

Table A1.1

Transducer #	Change in Radial	Change in Circumferential
86	.14°	.63°
88	.33°	.52°
89	.21°	.66°
114	.46°	.52°
95	.10°	.11°
100	1.15°	.27°
111	.35°	1.89°
125	.16°	.52°
128	.12°	.35°
167	1.38°	2.07°
197	1.30°	.54°
209	.11°	.24°
224	.09°	.22°
226	.56°	.18°
227	.30°	.32°
Mean Change $\bar{x}$	.45°	.60
Sample Std. Dev. s	.45°	.59

Appendix II

Connector Contact Selection

I. Evaluation Procedure

A major source of problems in the transducer assembly was intermittent electrical contact of the connector. The exact failure mode was not clear so tests were performed to isolate the problem. Two sets of contact pairs, representing generic contact types were evaluated. The types of contact represented were (Figure A-2.1):

1) spring socket with solid pin;

2) tubular socket with spring pin.

The withdrawal force of the assembled contact pair was measured as an indication of contact force. It was assumed that good electrical contact would be indicated by a high withdrawal force, because electrical contact relies on the mechanical interference of the connector parts.

Multiple pairs of pins and sockets were assembled for testing. The sockets were anchored to a test bed while the pins were withdrawn using a recording spring scale. The peak pull-out force was noted and recorded. The various pins and sockets were interchanged and multiple withdrawals were made to establish a statistical data base.

II. Results

The intermittent electrical contact was found to be due entirely to poor mating of the connector parts. The solid pin, spring socket combination that was in use was found to have the lowest and least reliable pin withdrawal force, while spring pins showed a consistently high withdrawal force. The statistical data are plotted as histograms in Figure A2.2. The solid pin,

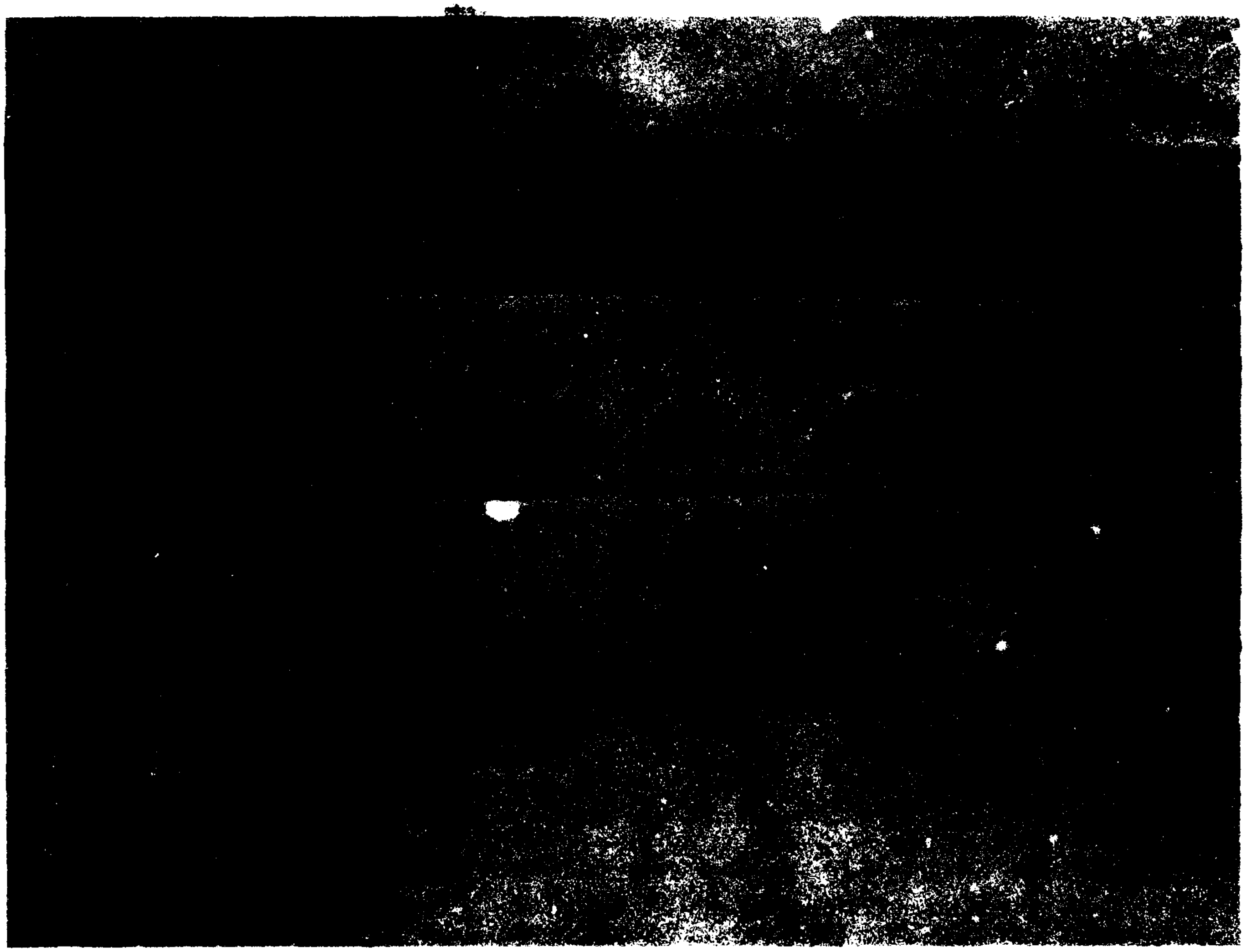

Figure A-2.1. Contact Pairs. Spring pin with tubular socket - top.
Solid pin with spring socket - bottom.

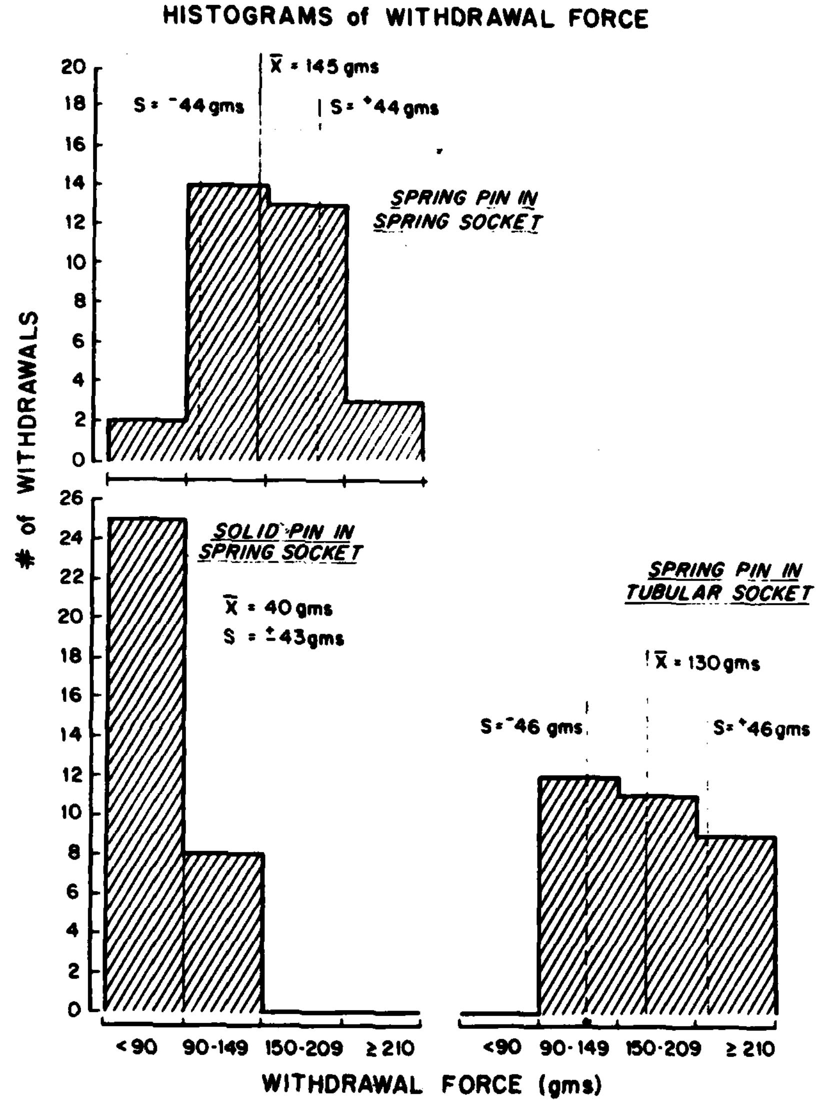

Figure A-2.2. Histograms of the force required to withdraw contact pins from mating sockets.

spring socket combination had the lowest average withdrawal force, but it also had a sample deviation greater than the mean. In practice, this means that a pin is more likely to fail than it is to succeed. The spring pins, however, were found to have more uniform characteristics, a trait which makes them more desirable. Even the worst performances of this type are better than the average solid pin. Our experience in the field has proved these results out. With over 1200 operational transducer months to date there have been no failures of the connector contacts. It is important to note that the pin and socket connection finally selected for manufacture had a mean withdrawal force of only 50 gms, but the standard deviation was a mere 5 gms. A consistent connector with moderate contact force is more than adequate for maintaining electrical continuity.

Appendix III

Components and Suppliers

I. Parts and Suppliers

1) Urethane

CONAP Incorporated
1405 Buffalo Street
Olean, NY 14760

Conap DP-10767	Transducer Body
Conap EN-4	Transducer Face

2) Electrical Contacts

ITT Cannon Electric
666 E. Dyer Road
Santa Ana, CA 92702

ITT Cannon 2D CTA Contacts
Male Pin: 031-9540-004
Female Socket: 030-9542-002
Gold plated with inspection hole

3) Piezoceramic Element

Transducer Products
95 Woolcott Avenue
Torrington, CT 06790

LTZ-2M Ceramic
3/8" O.D. x .050" thick All silver side is positive

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16. Abstract (Limit: 200 words)

The development of a reliable miniature molded transducer for the Williams/Koehler acoustic current meter, BASS (Benthic Acoustic Stress Sensor) is documented. The procedures developed and components selected for manufacturing the transducer assemblies are documented as well as some of those rejected.

Engineering tests performed to ensure reliable performance in the field are outlined and discussed as well.

The transducers are now routinely molded with great success (over 1200 operational transducer months to date) and commercial sources are being investigated.

17. Document Analysis a. Descriptors

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2. Acoustic
3. Transducer

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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